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REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: TOP 4-2-605
2. GOVT ACCESSION NO.: A110645
3. RECIPIENT'S CATALOG NUMBER:
4. TITLE (and Subtitle): US ARMY TEST AND EVALUATION COMMAND TEST OPERATIONS PROCEDURE "BALLISTIC MATCHING OF MAJOR CALIBER AND SPOTTER SYSTEMS"
5. TYPE OF REPORT & PERIOD COVERED: Final
6. PERFORMING ORG. REPORT NUMBER:
7. AUTHOR(s):
8. CONTRACT OR GRANT NUMBER(s):
9. PERFORMING ORGANIZATION NAME AND ADDRESS: US ARMY ABERDEEN PROVING GROUND (STEAP-MT-M) ABERDEEN PROVING GROUND, MARYLAND 21005
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: DARCOM-R 310-6
11. CONTROLLING OFFICE NAME AND ADDRESS: US ARMY TEST AND EVALUATION COMMAND (DRSTE-AD-M) ABERDEEN PROVING GROUND, MARYLAND 21005
12. REPORT DATE: 3 February 1982
13. NUMBER OF PAGES: 9
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office):
15. SECURITY CLASS. (of this report): Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE:

16. DISTRIBUTION STATEMENT (of this Report): Approved for public release; distribution unlimited.
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report):
18. SUPPLEMENTARY NOTES:
19. KEY WORDS (Continue on reverse side if necessary and identify by block number):

Ballistic Matching, Minor Caliber Weapons, Spotter Systems, Direct Fire Weapons, Mismatch, Major Caliber Weapons, Recoilless Rifles

20. ABSTRACT (Continue on reverse side if necessary and identify by block number):

Describes procedures for determining how closely the trajectory of a spotter system ballistically matches that of a larger direct-fire weapon.

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US ARMY TEST AND EVALUATION COMMAND
TEST OPERATIONS PROCEDURE

DRSTE-RP-702-103
*Test Operations Procedure TOP 4-2-605 3 February 1982
AD No. A110645

BALLISTIC MATCHING OF MAJOR CALIBER AND SPOTTER SYSTEMS

1. SCOPE. This TOP provides detailed tests to optimize the closeness with which the trajectory of a spotter weapon ballistically matches that of a larger direct-fire weapon over the combat ranges of interest. Such a system has been used with the 106-mm recoilless rifle.

One method that may be employed to increase the probability of first round hits by major caliber weapons is to first fire "spotter" rounds from a minor caliber weapon firing tracer ammunition. This minor caliber weapon is permanently biased in both azimuth and elevation relative to the major caliber weapon so that when fired at a pre-established muzzle velocity, its hits will match those of the major caliber weapon at an intermediate range distance termed the "crossover point".

Under these conditions, a degree of ballistic "mismatch" will occur at shorter and longer ranges. The objective of a ballistic match test is to generate ballistic data required for computing the optimum choice of aiming bias and muzzle velocity for the spotter weapon, and to provide test confirmation of the results of these computations. A further objective is to provide test data for evaluating the associated fire-control sighting system.

*This TOP supersedes TOP/MTP 4-2-605, 10 June 1968.

2. FACILITIES AND INSTRUMENTATION.

2.1 Facilities.

ITEM	REQUIREMENT
Firing range, direct fire	2000 m long, or as required
Ammunition	Major caliber and spotter rounds
Targets	Large enough to contain dispersion of weapon being fired; plywood for smaller caliber and cloth for larger
Firing tables	For major caliber weapons

2.2 Instrumentation.

ITEM	MAXIMUM PERMISSIBLE ERROR OF MEASUREMENT*
Boresight equipment	± 0.1 mil
Counter chronographs	± 1 microsecond
Velocity solenoid coils, lumiline screens, sky screens, or muzzle velocity doppler radar	velocity to 3000 m/s, ± 0.1%
High speed cameras (slit, smear, or streak)	velocity to 3000 m/s, ± 0.1%
Hawk velocimeter	continuous velocity to within 0.1%
Distance-measuring devices (calibrated steel measuring tape)	within ± 3 mm
Anemometers and wind vane	± 3 km/hr

3. PREPARATIONS FOR TEST.

a. Lay out the test range to include:

(1) Placement of lumiline screens for measuring instrumental velocity, from which muzzle velocity of the spotter round is extrapolated (see TOP 4-2-805)[1]**

*Values may be assumed to represent ± 2 standard deviations; thus, the stated tolerances should not be exceeded in more than one measurement of 20.

**Footnote numbers correspond to reference numbers in Appendix B.

(2) Placement of velocity solenoid coils for measuring instrumental velocity, from which muzzle velocity of the major caliber weapon is extrapolated. A muzzle velocity radar may also be used.

(3) Placement of sky screens for measuring projectile arrival times at the down-range target (see paragraph 5.1.1.e)

(4) Placement of sky screens for timing projectile passage or indicating trajectory points corresponding to one-half and three-fourths of the target distance

(5) Placement of Hawk velocimeter to the rear and slightly to the side of the weapon

(6) Placement of anemometers at several locations down range from the gun site. The anemometers should be placed at or near the gun, the trajectory maximum ordinate, and the target.[2] For moderate- and slow-velocity projectiles at ranges of 2000 meters and more, 4 or 5 anemometers should be considered.

(7) Provisions for adequate protection for personnel and equipment have been made

b. Ensure the safety and operability of the weapons and ammunition by inspection

c. If possible, perform all firing on the same day to minimize variables.

3.1 Data Required. Record the following:

a. Data pertaining to major caliber and spotter weapons:

(1) Gun caliber, model, and serial number
(2) Mount caliber, model, and serial number
(3) Tube land diameter in mm
(4) Tube round number

b. Data pertaining to ammunition for major caliber and spotter weapons:

(1) Propellant lot number, type, manufacturer, and year made
(2) Projectile model and lot number
(3) Weight of each projectile
(4) Propellant weights
(5) Primer model and type
(6) Fuze model and lot number
(7) Cartridge case model and lot number

4. TEST CONTROLS.

a. Review all instructional material (including system support packages) issued with the test item, and review reports of previous tests on similar items.

b. Review the safety statement provided by the developer to determine whether any hazards have been identified. If hazards do exist, write the test plan to include subtests suitable for evaluating them.

c. Make sure applicable Standing Operating Procedures (SOPs), prepared in accordance with DARCOM regulations, are at the test site. Observe SOPs during testing.

d. Make sure all test instruments have been calibrated to within desired tolerances.

e. Connect chronographs to sensing devices, as appropriate, and calibrate before testing.

f. Connect recording instrumentation as appropriate, and calibrate before testing.

5. PERFORMANCE TESTS.

a. Before testing, magnetize projectiles to be fired through solenoids. Magnetize them sufficiently to deflect a compass 45° from the earth's magnetic field when the compass is held at a distance of about 10 cm from the projectile.

b. Temperature-condition ammunition to 21° C to represent standard conditions. NOTE: If there is reason to believe that temperature will affect the ballistic match, firings will also be conducted at -46° and 63° C.

5.1 Test I: Approximate Spotter Velocity, and No Bias Angle.

Prior information on the ballistics of the major caliber weapon and the spotter weapon will be assembled so that a tentative muzzle velocity can be established for the spotter weapon. Such information is necessary to make it possible to obtain suitable impacts at the crossover point, before initiating the test described below.

5.1.1 Method.

a. Place a vertical target at a down-range distance of about two-thirds of the maximum usable range of the weapon/spotter system (or at whatever range is designated as the crossover range).

b. Energize the instrumentation, and fire both major caliber and spotter rounds against the vertical target to determine elevation to achieve hits on the target. Spotter and major caliber bores shall be parallel for this test. Change the elevation, if necessary, to obtain one good hit on the target with the major caliber weapon and 2 to 5 good hits with the spotter weapon.

c. Fire for record 20 spotter projectiles and 5 to 10 major caliber projectiles at the elevation determined above.

d. Make velocity measurements in accordance with TOP 4-2-805.

e. Measure air temperature, atmospheric pressure, and humidity every 60 minutes near the firing site. Measure wind velocity and direction by taking anemometer and wind vane readings as close as possible to the instant the projectile passes the instrumentation (positioned in accordance with paragraph 3a(6)) and observing discontinuities in the recorded wind data that coincide with the passage of the projectile.

5.1.2 Data Required. Record the following:

a. Muzzle velocities and flight times, using velocity solenoid coils, sky screens, lumiline screens, chronographs, and recorders

b. Meteorological data as obtained in paragraph 5.1.1.e

c. Target distances from the muzzle of each weapon (meters)

d. Elevation of major caliber and spotter systems (mils)

e. Measured velocities and flight times

f. Horizontal and vertical positions of target impacts with respect to aiming point

g. Initial bias angle (zero degrees) between major and spotter systems

5.1.3 Computation. Submit data to ballisticians to obtain center of impacts before and after wind correction1 and to calculate an elevation bias angle, deflection bias angle, and change in muzzle velocity of the spotter would serve as a first approximation to minimize mismatch at the target range.

5.2 Test II: Optimum Spotter Velocity and Bias Angle for Minimum Mismatch.

5.2.1 Method.

a. Load spotting rounds to achieve muzzle velocity of paragraph 5.1.3.

b. Adjust elevation and deflection bias angles of spotting weapon to that determined in 5.1.3.

c. Fire the spotter weapon system to achieve impacts on a vertical target placed at two-thirds effective range.

d. Obtain a 20-round group of hits with the spotter weapon on the target.

e. Fire the major caliber weapon to obtain a 5-round group of hits on the same target, maintaining the elevation and deflection bias used above. NOTE: If necessary, adjust the spotter and major caliber weapons together, but do not adjust the bias angle.

f. Increase the elevation of the major caliber weapon and spotter weapon to impact a target at the maximum usable range, in accordance with the range tables of the major caliber weapon. Maintain the same bias in elevation and deflection angle as before. Fire 20 spotter rounds and 5 major caliber rounds at the target.

g. Decrease the elevation of the spotter and major caliber weapons to impact a target at one-third of the usable range, in accordance with the range tables of the major caliber weapon. Maintain the same bias for elevation and deflection angles as before. Fire 20 spotter rounds and 5 major caliber rounds at the target.

h. Submit the data to ballisticians in accordance with paragraph 6.

5.2.2 Data Required.

a. Measure and record meteorological conditions, muzzle velocities, times of flight, projectile weights, spotter weapon elevations, bias angles, ranges to vertical targets, and impact coordinates for each projectile impact.

b. Record data as required in 5.1.2.

c. Record bias angle of the spotting weapon as in 5.1.2.

6. DATA REDUCTION AND PRESENTATION.

Submit data recorded in 5.1.2 and 5.2.2 to ballisticians to compute optimum elevation and deflection bias angle between major caliber and spotter weapons, plus any change in spotter caliber velocity required for minimum mismatch. Ballisticians will also tabulate the mismatch at a number of ranges. Compare results with specifications prescribed for the system, and record or note any limitations. NOTE: The possibility exists that after the firing and computations described above are completed, the changes recommended for muzzle velocity, elevation bias and deflection bias may be of such a magnitude that re-running the test in paragraph 5.2, using new bias angles and muzzle velocity, is warranted.

See Appendix A for a discussion of the principles involved in matching trajectories.

APPENDIX A

PRINCIPLES INVOLVED IN MATCHING TRAJECTORIES

The objective of a ballistic match test is to generate ballistic data required for computing the optimum choice of aiming bias and muzzle velocity for the spotter weapon, and to provide test confirmation of the results of these computations. A further objective is to provide test data for evaluating the associated fire-control sighting system.

It might appear at first glance that major caliber and spotter systems could be matched by firing both at the same quadrant elevation and velocity. As shown by the following considerations, however, this would require a spotter round of inordinately high density. To a first degree of approximation, the deceleration of projectiles having the same velocity will vary directly as the cross-sectional area and inversely as the mass, i.e.,

$$(1)\quad a = K \frac{\text{Area}}{\text{Mass}} = K \frac{\pi r^2}{\pi r^2\ k r \rho}$$

when a is deceleration; K is the proportionality constant; r is the radius of the projectile; k is the fixed ratio of length to radius of a hypothetical cylinder having the same volume as the projectile; and ρ is the projectile's "average" density (projectile mass/projectile volume). For projectiles having the same proportional shape, K and k would remain constant. Thus, the ratio of decelerations for two projectiles having the same shape but different radii and densities would be:

$$(2)\quad \frac{a_2}{a_1} = \frac{r_1\ \rho_1}{r_2\ \rho_2}$$

This relationship may be used to compare the decelerations experienced by identically shaped 105-mm and caliber .50 projectiles traveling at the same initial velocity,

$$(3)\quad \frac{a_2}{a_1} = \frac{52.5\text{ mm}\ \rho_1}{6.35\text{ mm}\ \rho_2}$$

$$= 8.27\ \frac{\rho_1}{\rho_2}$$

Thus, if the average density is the same for each projectile, deceleration of the caliber .50 projectile will be more than 8 times that for the 105-mm projectile. The ratio of the decelerations could be held at unity by manufacturing a caliber .50 projectile 8 times denser. While this may be impossible, the use of high density materials such as tungsten carbide or depleted uranium will help. Assuming the caliber .50 projectile has inadequate density, the 105-mm projectile will outdistance the caliber .50 model as to range, given the same initial muzzle velocity and gun elevation. This hypothetical example shows that it is necessary to fire the spotter round at a greater velocity, angular elevation, or both, in order to approach a ballistic match.

Practically, the spotter round is generally fired with both a higher muzzle velocity and a higher quadrant elevation (via bias) than the major caliber round,

the exact values having been chosen to optimize the degree of ballistic mismatch over ranges that extend to the maximum range specified for spotter round use. Under these circumstances, the two rounds are ballistically matched at the cross-over point generally found at some two-thirds the maximum usable range. Spotter rounds against closer targets will strike slightly high relative to the major caliber round, and slightly lower for the more distant targets.

The selection of bias angle and spotter muzzle velocity depends on where the trajectory crossover is desired. The mathematical approach is to use expressions of mismatch for those values of elevation bias angle and muzzle velocity that give a minimum mismatch over the ranges of interest.

APPENDIX B

REFERENCES

1. Test Operations Procedure (TOP) 4-2-805, Projectile Velocity Measurements, 23 April 1979.

2. Mark, Harris J. and Heppner, Leo D., "Final Report on Methodology Investigation of Improved Wind Corrections for Accuracy Tests", US Army Aberdeen Proving Ground. Report No. APG-MT-4642, May 1975.

3. Groves, Arthur D., "Method for Computing the First Round Hit Probability for an Antitank Weapon with Spotting Rifle Control", Aberdeen Proving Ground, BRL Memorandum Report 1450, January 1963.

4. Watson, G.T., "Report on Engineering Tests of Cartridge, Spotter System", US Army Aberdeen Proving Ground, Report SPS-TSA-4020/25, September 1958.